overhead values like this are used in both Professor Pickholtz's and Professor Schmalensee's arguments against time sharing, it can be seen that while there is some price being paid for complexity, direct capital cost, "difficulty", and system capacity reduction, it is small and manageable for any "reasonable" number of market entrants.

Professor Pickholtz suggests that certain features of a system's performance may be slowed down under timesharing. However, the magnitude of any slowdown depends upon the sharing algorithm. The slow-down effects are worst in the case of the very simplest mechanism for sharing the band: round-robin time division with fairly large time slices (several seconds or more). Of course, the time slices can be much smaller, as Pinpoint's system results prove, and need not be strictly round-robin.[16] Other mechanisms, like forward scheduling, have even more capability of addressing most of Professor Pickholtz's objections. This involves scheduling time slots for the sharing systems dynamically in the future, typically several seconds in advance. Scheduling can potentially be much further in advance for regular, periodic events, such as security monitoring.

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[16] Token-passing may be an effective mechanism for local area networks with very reliable and fast (small latency) communication mediums (typically a copper or fiber bus). But it is not a suitable mechanism for widely dispersed control centers of wide-area AVM operations where the token passing is less secure and subject to significant propagation delay latencies. Consequently it is unlikely that it will ever be implemented as a viable sharing control mechanism.

Professor Pickholtz also looks at the perceived need for "asynchronous" operations. "Asynchronous" operations relates only to the perceived performance of the system by the user, i.e., the latency between a request for action and the response to it. With an appropriate, synchronized protocol structure, latency delays for "priority" activities can be easily reduced to manageable proportions consistent with any demand for asynchronous operation.

In his analysis, Professor Pickholtz states that adding a second cellular operator to the cellular band only increased the network infrastructure costs by 15%, but that adding a second LMS operator would purportedly add more than 100% to the cost. Pinpoint wonders where the second cellular operator got its system so cheaply. The second entrant apparently had to build out its system fully (i.e., at roughly a full 100% of the cost of the first cellular system). Furthermore, the incremental increase in system operating cost depends on system loading, implying that it is at its maximum when the system is installed and there is only one marginal consumer of its services. As the volume of services increases, the marginal cost goes down. Therefore cost will increase nearly equally whether using time-sharing or frequency sharing, but a competitive marketplace created by time-sharing will justify such expenditures.

PacTel makes light of frequency sharing at less than 8 MHz, but glosses over the fact that throughput varies as the square of occupied bandwidth (for a white gaussian noise limited communication channel) or, as Pinpoint has shown is more likely to be the case in this band, as the cube of the occupied bandwidth (for the narrowband interference limited environment). Professor Pickholtz's position threatens to hide a very significant factor for efficient use of the band. The implication of the relationship is (generally) that to maximize the service value of the band, an operator should have access to the greatest amount of available bandwidth so that the service it is offering can be completed in the shortest time.[17] There are other factors affecting the position-fixing rate, like maximum-range signal flight times and minimum protocols overhead times that set practical limits on the maximum amount of spectrum that can usefully be utilized, but these do not overcome the benefits of maximizing bandwidth.

Modeling has shown that many practical systems can effectively make use of up to the full 26 MHz without incurring spectrum wasting. However, to obtain quality access to the band, each user needs to have exclusive (amongst wide-band, wide-area, LMS service providers) access to the band *while they use it*. Multiple entry can be accommodated consistent with this principle in one-way: time-sharing. At the transmit power levels that wide-area LMS service providers must necessarily operate at, in

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[17] See Figure 12 for an illustration of the bounds around practical position fixing system designs.

order to operationally tolerate the low-powered, local-area service providers, the record suggests that wide-area operators cannot practically share spectrum by any other known co-channel operating technique, like CDMA or frequency hopping, other than frequency division. But this is not co-channel sharing and would impose severe capacity limits as the band is split to support two or more competitors.

Both the Teletrac and proposed METS radiolocation technologies used PSK modulation schemes with approximately 2 Mch/s chipping rates. They claim that they require at least 8 MHz of spectrum within which to contain the resulting signals "economically". They claim that it may even be impossible or infeasible to implement filters to adequately contain the signal to the bandwidth of the "main lobe", of about 4 MHz nominal bandwidth. The cost of their assertion is that between them 8 MHz of spectrum is being used for "guard band" for poor engineering! Contrary to the claims of both METS & Teletrac, it is entirely possible to build filters to effectively contain the transmitted bandwidth to about twice the chipping rate. In Pinpoint's experimental system, now in operation in Washington, D.C., such filters are used to contain more than 99% of the energy of an 11 Mch/s MSK signal, with a 10 MHz 3 dB bandwidth, to within the allocated 16 MHz experimental bandwidth. (The same filters also help to reduce the interference from other 900 MHz signals that are close to the 928 MHz band edge.) The engineering practices imbedded in the technological approaches such as those espoused by Teletrac and METS should not dictate the use of very scarce spectrum, simply because it is difficult, to achieve certain cost goals.

H. A Personal Locator Service Should Not Drive the FCC's Band Plan

Teletrac has suggested that a personal locator service is an important component of AVM service in the 902-928 MHz band. This contention should be considered according to the overall technical, functional and marketing performance requirements and market size to be addressed.

A vehicular location system, operating as it does from an adequate power source in the vehicle's electrical system, and being carried within or attached to the vehicle, needs to be able to perform the radiolocation function very quickly because of the extremely large number of vehicles requiring service from the system, as discussed above. In certain situations, the location function must occur quickly to meet the needs of some vehicular application for short response times, *i.e.*, "asynchronous-like" operation.[18] The radiolocation function also needs to be performed efficiently to minimize the loss of airtime due to protocols and the time needed to recover low-power signals from

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[18] As discussed above, the needs for "asynchronous-like" operation are not in conflict with time-division sharing by wide-area systems.

low signal-to-noise ratios. The Cramér-Rao bound shows that to reduce the time necessary to perform a vehicular position fix, the power levels of signal across the terrestrial radiolocation area must be increased relative to ambient noise and interference, especially the power radiated by the mobile, so as to reduce the base station's receiver processing time and to increase the network throughput. This is consistent with the availability of power from the mobile's source, the vehicle itself. The equipment used for vehicle radiolocation does not need to be extremely small nor power miserly. Additionally, the radiolocation will usually be done in conjunction with the operation of a separate or integrated radio data system.

In contrast, a personal locator must be small, light and have extremely modest power requirements. A locator typically does not require the operation of a data system like that required by vehicular applications unless it is really intended as a substitute for paging.[19] The traffic volume, *i.e.* number of position fixes, required for vehicles, is many orders of magnitude higher than the number of "lost persons", or "things" (*e.g.* stolen vehicles) being searched for at any given time. The time taken to perform a position fix on a person can be very long and still be acceptable. This is consistent with battery

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[19] There are, however, several devices on the market now (*e.g.* cellular and display paging) and soon to come (*e.g.* PCS and two-way paging) that serve personal communications requirements quite well.

operated equipment operating at low output power. Moreover, since a longer time can be taken, considerably less bandwidth is sufficient.

Given these very significant differences, the design and implementation of the efficient vehicular location and management systems would be at great odds with the incorporation of a personal locator functionality in the same systems. Accordingly, personal location and other low power applications -- such as stolen vehicle tracking and law enforcement applications noted by Teletrac -- could be permitted by the FCC, but in a narrowband allocation, possibly outside the AVM allocation, where low background noise levels can allow battery-powered equipment to operate successfully.[20] The desire of one market participant to implement an incompatible personal location system should not hold hostage the competitive implementation of efficient high-speed vehicular systems in the noisier 902-928 MHz AVM band.

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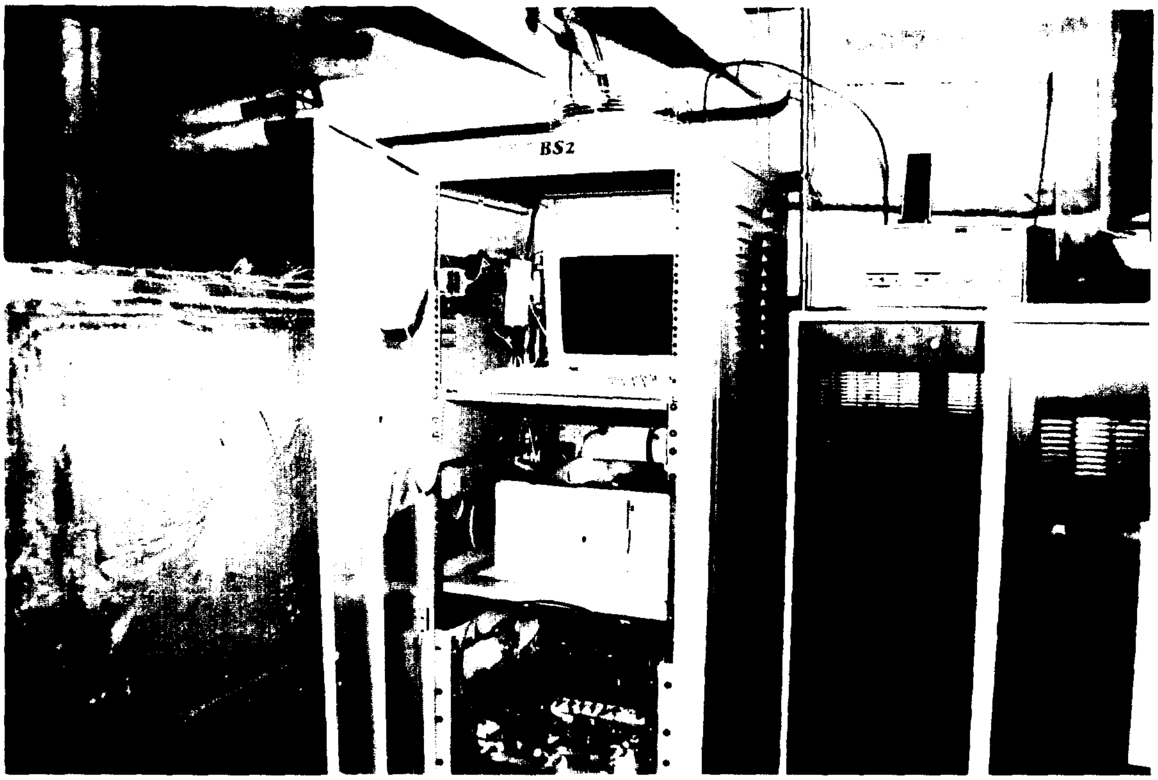
[20] For example, some of the reserve spectrum from the FCC's recent narrowband PCS allocation at 901-902, 930-931, and 940-941 MHz could be used for such a service. It should also be possible to make such a service a reality in the 906-910 and 920-924 MHz low noise sub-bands Pinpoint proposed, provided that the operator were willing to devote a substantial amount of its "time resource" to such a use.

Dispatching Center (left) and Map Display (right):
Data Communications are Tracknet™ Capable

Experimental System Network Control Center

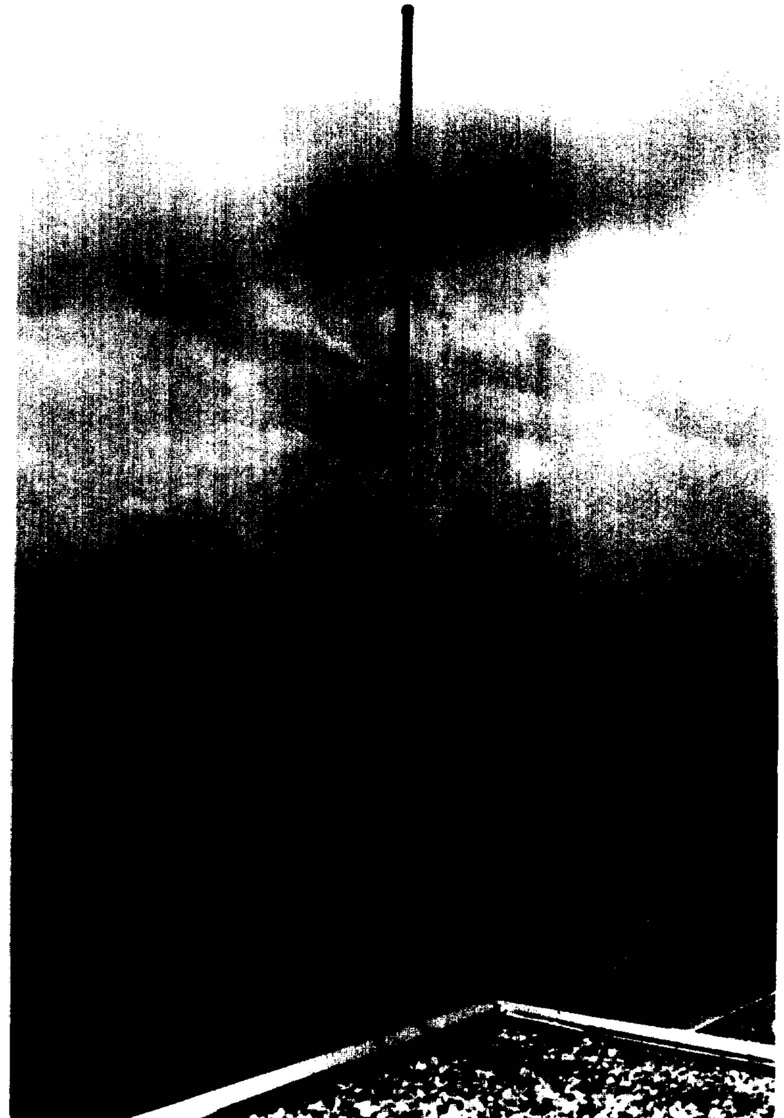
↑	↑	↑	↑
Diagnostic CPU	Navigation CPU	Scheduling Control	Data Communications CPU



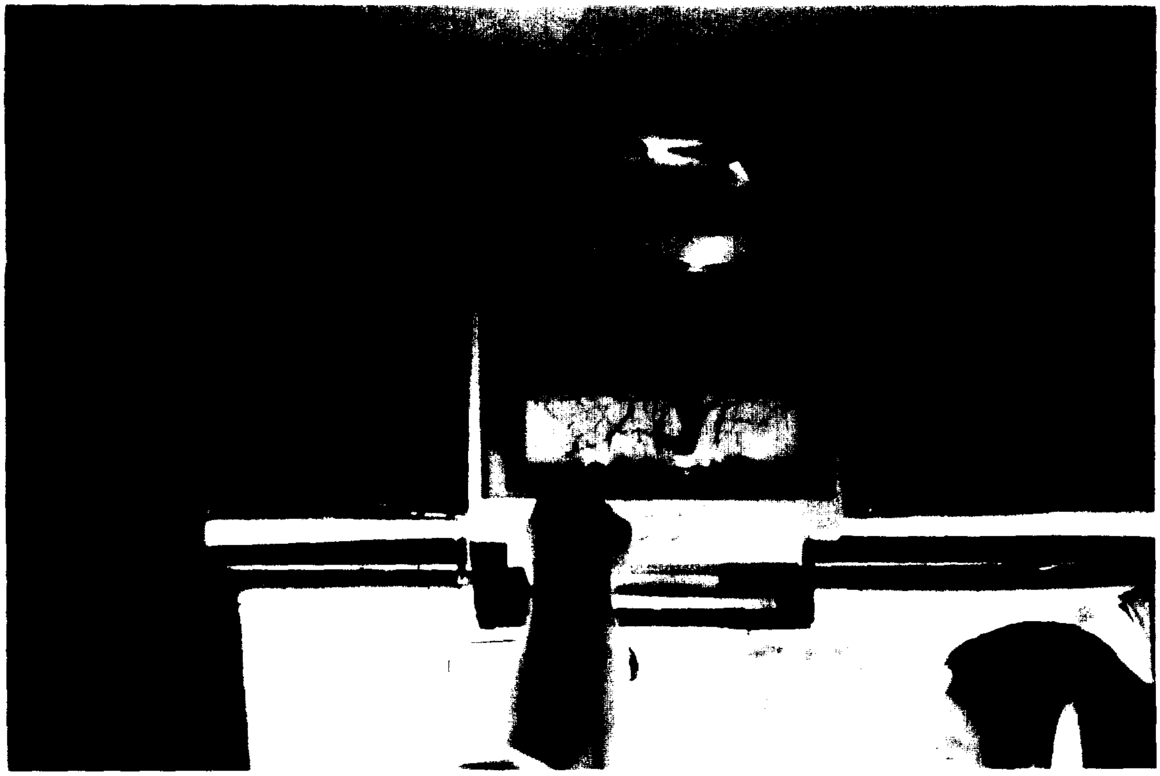
Base Station No. 2
U.S.A. Today Building

Columbia Plaza Base Site

Columbia Plaza Site
(Viewed toward Key Bridge)



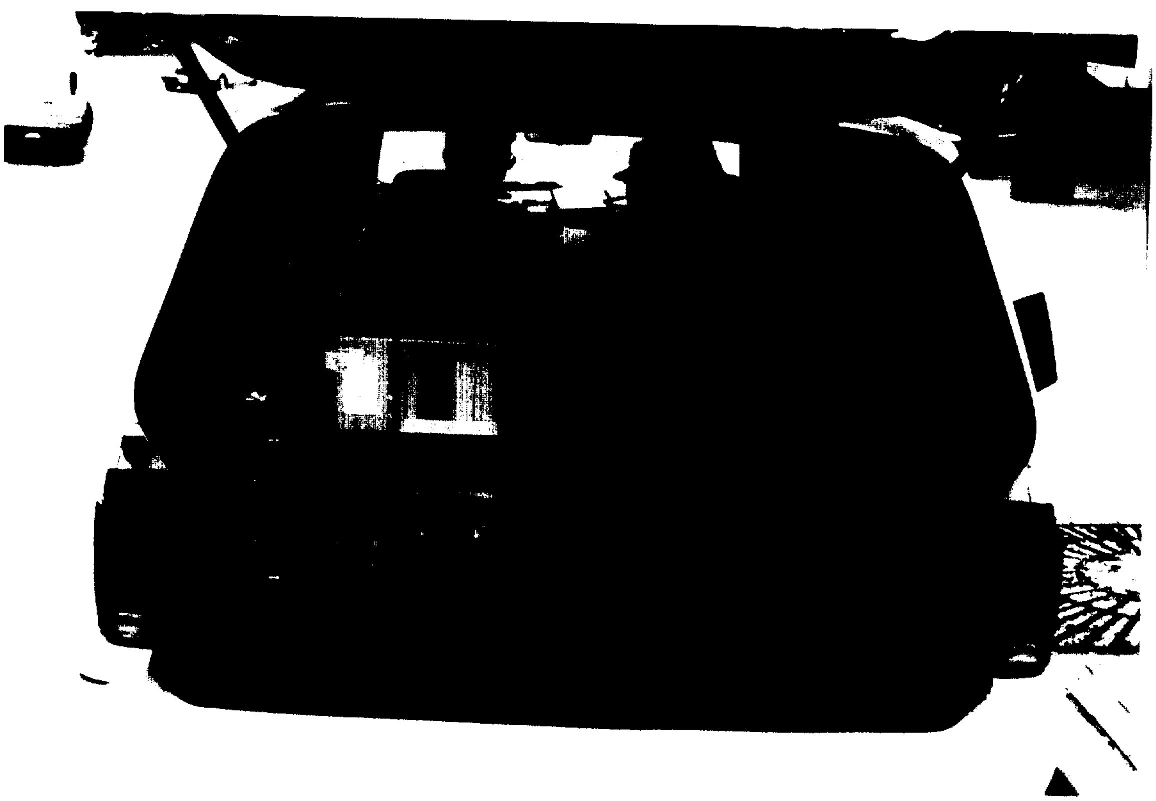
Crystal City Site
(Viewed Toward National Airport)



Mobile Application Terminal (MAP) - TRACKNET™

Portals Site

Mobile Demonstration Unit



Mobile Unit with Data Logging System for Coverage Evaluation

Table 1

Demographics & Traffic Charateristics of five Metropolitan areas (1990)

DEMOGRAPHICS	Baltimore	Minn-St.Paul	Phoenix	San Diego	St Louis	Average
Population (000's)	1991	2055	1920	2294	1950	2042
Square miles	765	956	971	680	694	821
Persons per sq mile	2603	2063	1977	3374	2810	2487
MILAGE						
Freeway & Expressway	237	294	98	230	268	225
Principal Arterials	406	132	731	243	529	408
Minor arterials	512	916	536	764	679	681
Collectors & Local	4793	7609	6031	4461	5690	6117
Total Freeways & Arterials	1155	1342	1385	1237	1474	1315
Total all roads	5948	8951	9396	5698	7164	7431
Freeways per sq mile	0.31	0.3	0.1	0.34	0.38	0.27
Freeway & Arterial per sq mile	1.51	1.35	1.41	1.52	2.12	1.6
Roadway miles per 1000 people	3	4.4	4.9	2.5	3.7	3.6
DAILY VEHICLE MILES TRAVELLED (VMT)		(Millions)				
Freeways & Expressways	15.8	17.8	7.9	27.7	18.4	17.5
Principal Arterials	9.8	3.5	17.5	6.8	11.2	9.8
Minor Arterials	5.7	11.3	4.7	10.7	7.7	8
Collectors & Local	5	10.4	9.5	6.4	8	7.9
Total Freeways & Arterials	31.4	32.8	30.1	45.2	37.3	35.9
Total Daily VMT	38.4	43.2	39.7	51.6	45.3	43.2
OTHER STATISTICS						
Freeway & Arterials DVMT/Milage (000s)	27.2	24.4	22.1	36.6	25.3	26.9
Freeways as % of total Milage	0.04	0.03	0.01	0.04	0.04	0.03
% DVMT served by Freeways	0.43	0.41	0.2	0.54	0.41	0.41
Freeways & arterials as % of total milage	0.19	0.15	0.15	0.22	0.21	0.18
% of DVMT on freewways & arterials	0.85	0.76	0.76	0.88	0.82	0.82

Table 2	Area-wide daily & Peak period Traffic data			
Variable	**Value**	**Units**	**Code**	**Basis**
Area-Wide Traffic				
Population of metro area	2000	000s	Pop	Based on 5 metro areas (4.1)
Size of metro area	820	sq miles		Based on 5 metro areas (4.1)
Miles of Freeways & arterials	1315	miles		Based on 5 metro areas (4.1)
Avg. side of sq grid for area	28.6	miles		
Number of Automobiles	1140	000s	Autos	=0.57 * Pop
Number of Vehicles	1530	000s	Veh	=1.34 * Autos
Trips/Vehicle/day	3		TVD	Estimated
Avg trip length	9.5	miles		Estimated
Total daily vehicle trips	4580	000s	Trips	= Veh * TVD
Total daily VMT	43.5	millions	DVMT	= Trips * TripLength
Peak Period				
Duration of AM or PM Peak Period	3	hours	PL	Estimated
Fraction of VMT in Peak Period	0.3		PkFr	Estimated
VMT in Peak Period	13.1	million	pkVMT	= DVMT * PkFr
Avg. Speed in peak	25	mph	Spd	estimated
Avg. trip length in peak	11	miles	TL	estimated
Avg. trip duration in peak	26.4	min	TT	= Spd * TL
Number of trips in peak period	1190	000s	PkTp	= pkVMT/TL
Trip Rate during peak	6600	per minute	Rate	= PkTp/PL
Steady state time within peak	20	minutes	M	Est. Steady State: > cycle time; < Avg. trip time
Avg. number of vehicles on road during peak (steady state)	174	000s	VoR	= Rate * TT
Fraction of peak VMT on major roads (frewways & arterials)	0.82		FVMR	estimated
Incidents per vehicle in M minutes	0.00013		IVM	Derived from 16 million VMT
Number of reportable incidents on major roads in M minutes	19			IVM * VoR * FVMR

Table 3

Model of expected position fixing rates to satisfy requirements of effective IVHS Traffic Monitoring and Management

TRAFFIC ASSUMPTIONS

Model Metro Population — Millions	1	2	4	6
Population Per Square Mile	3,200	3,200	3,200	3,200
City area - sq miles	313	625	1,156	1,875
Approximate City radius - miles	10	14	19	24
Approximate number of base stations per city	30	50	80	110
Number of independent radio-location clusters	2	4	7	9
Vehicles Per Million Population	771,000	1,542,000	2,852,700	4,626,000
Number of trips in each of two 3 hour peak time	595,000	1,190,000	2,201,500	3,570,000
Metro aggregate hours traveled in each 3 hr peak	261,800	523,600	968,660	1,570,800
Metro aggregate miles traveled in each 3 hr peak	6,545,000	13,090,000	24,216,500	39,270,000
Average # of vehicles on all roads during peak time	87,267	174,533	322,887	523,600
Average speed during peak period	25	25	25	25
Average trip time during peak hrs — minutes	26	26	26	26
Average trip distance during peak hrs — miles	11	11	11	11
Average trips per vehicle per day	3	3	3	3
Average distance between vehicles on all roads - ft.	213	213	213	213
Principal Arterial miles per million pops	204	408	755	1,224
Secondary Arterial miles per million pops	341	681	1,260	2,043
Major Freeway & Expressway Miles per million pops	113	225	416	675
Collector & local miles per million pops	3,059	6,117	11,316	18,351
Total of all road miles per million pops	3,716	7,431	13,747	22,293
Average Traffic Lanes in each direction: Freeways & expressways	3	3	3	3
Average Traffic Lanes in each direction: Principal Arterials	2	2	2	2
Average Traffic Lanes in each direction: Secondary Arterials	1	1	1	1
Average Traffic Lanes in each direction: Collector & Local roads	1	1	1	1
therefore - Total Lane miles per Metro area	4,145	8,289	15,335	24,867
Assumed Vehicles required per Lane-Mile with IVHS location capability - to provide adequate sampling density	1	1	1	1
therefore instantaneous number of vehicles required for traffic monitoring	4,145	8,289	15,335	24,867
% of all active (on the road) vehicles participating	**4.7%**	**4.7%**	**4.7%**	**4.7%**
Estimated % of all Metro-area vehicles equipped to satisfy IVHS monitoring based on probability that 50% of the "samplers" will be fleet vehicles	**2.4%**	**2.4%**	**2.4%**	**2.4%**
Estimated # of Metro-area vehicles equipped to satisfy IVHS	18,839	37,677	69,703	113,032
Guestimated # of dual-position fixes (for velocity @ location) per mile	3	3	3	3
Equivalent fixes per minute per sampling vehicle - (Note that transit systems are averaging polling rates at about 2 per minute per vehicle)	2.50	2.50	2.50	2.50
Peak position fixes per hour	621,675	1,243,350	2,300,198	3,730,050
Peak-period IVHS Traffic Monitoring Position Fixes/sec	**173**	**345**	**639**	**1,036**

Table 4

Model of expected packet messaging rates to satisfy requirements of effective IVHS Traveller & Traffic Information Systems

DATA ASSUMPTIONS

Message size assumptions - bytes	Out-bound	In-bound	rate - per	unit
Public Safety message with directions	500	10	2	hr
Public Safety message without directions	80	10	2	hr
Dispatch message with directions	500	20	2	hr
Dispatch message without directions	80	20	2	hr
Traveller Info message — initial	1000	100	1	trip
Traveller info message — re-route	500	50	0.5	trip
Broadcast message - incidents	350		5	hr
Bus Scedule message	200	50	1	hr
Busy period duration in Hours	3			
Assumed Bytes per packet	20			
% of all non-fleet vehicles IVHS capable	3%			
% of all fleet vehicles (other than Safety & Transit) IVHS capable	10%			
% of Public Safety & Transit fleets active during peak period	90%			
% of Commercial & Other fleets active during peak period	12%			
% of other vehicles using traveller info during peak period	50%			
Transit update rate (per minute)	2			

Traveller Information Systems Data Traffic

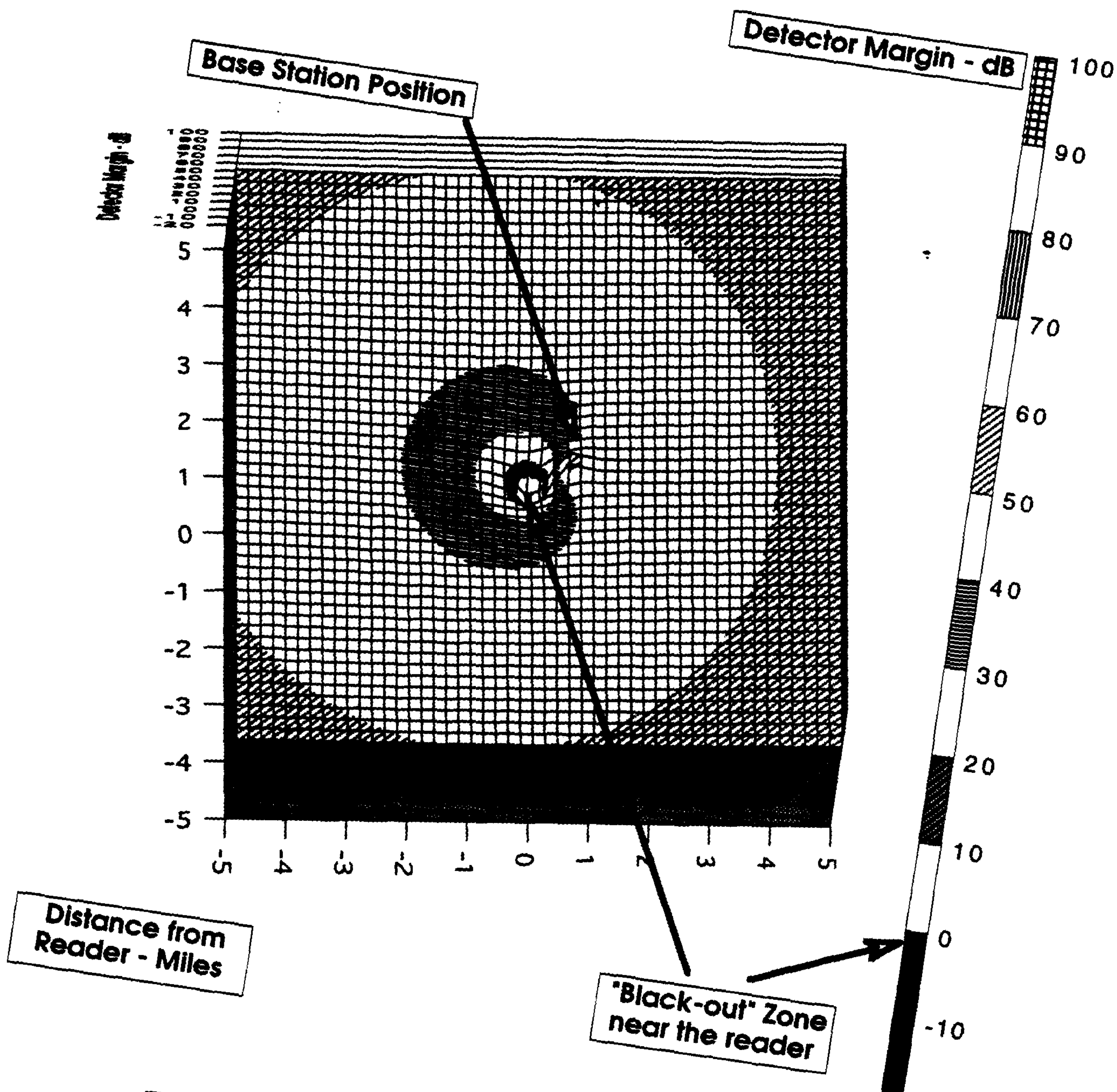
Model Metro Population — Millions	1	2	4	6
Public Safety Vehicles	1,200	2,400	4,440	7,200
Busses and transit vehicles	600	1,200	2,220	3,600
Vehicles in Commercial fleets with 4 or more vehicles	99,000	198,000	366,300	594,000
Vehicles in business fleets with < 3 vehicles or Govt fleets	69,000	138,000	255,300	414,000
Total active fleet vehicles	21,780	43,560	80,586	130,680
Total active other vehicles	65,487	130,973	242,301	392,920
Total active fleet vehicles using IVHS Information systems	2,178	4,356	8,059	13,068
Other vehicles using traveller information systems	1,965	3,929	7,269	11,788
% of Total metro vehicles IVHS capable	**4.5%**	**4.5%**	**4.5%**	**4.5%**
instantaneous % of vehicles active during peak period that are IVHS capable	**0.5%**	**0.5%**	**0.5%**	**0.5%**
Public Safety not including data-base retreval - data pkts per peak period	773,182	1,546,364	2,860,773	4,639,091
Fleet - data packets during peak period	519,750	1,039,500	1,923,075	3,118,500
Transit - data & update packets during peak period	212,220	424,440	785,214	1,273,320
Other non-fleet - data packets during peak period	321,480	642,960	1,189,476	1,928,880
Broadcast & Other IVHS - data pkts during peak period	285	570	1,055	1,710
Total airtime packets (time-slots) per hour	608,972	1,217,945	2,253,197	3,653,834
Total IVHS info-system requirements (time-slots) pkt/s	**169**	**338**	**626**	**1,015**
Total IVHS Radio-locating Comm System requirements - Sum of Monitoring & Traveller Information - pkt/s	**342**	**684**	**1,265**	**2,051**
Total IVHS Data requirements - Approx equivalent bits/second with no allowance for radio-location by alternate location technologies like GPS	68,369	136,739	252,966	410,216

Table 5 — **Effects of Communication system overheads on overall subscriber capacity & cost**

	% overhead	1.00	Aggregate Subsciber Capacity		1,000,000
# of Firms timesharing	1	2	4	8	16
Capacity/firm	1,000,000	500,000	250,000	125,000	62,500
overhead each	10,000	10,000	10,000	10,000	10,000
Aggr Cap	1,000,000	990,000	970,000	930,000	850,000
decrease %	0.0%	1.0%	3.0%	7.0%	15.0%

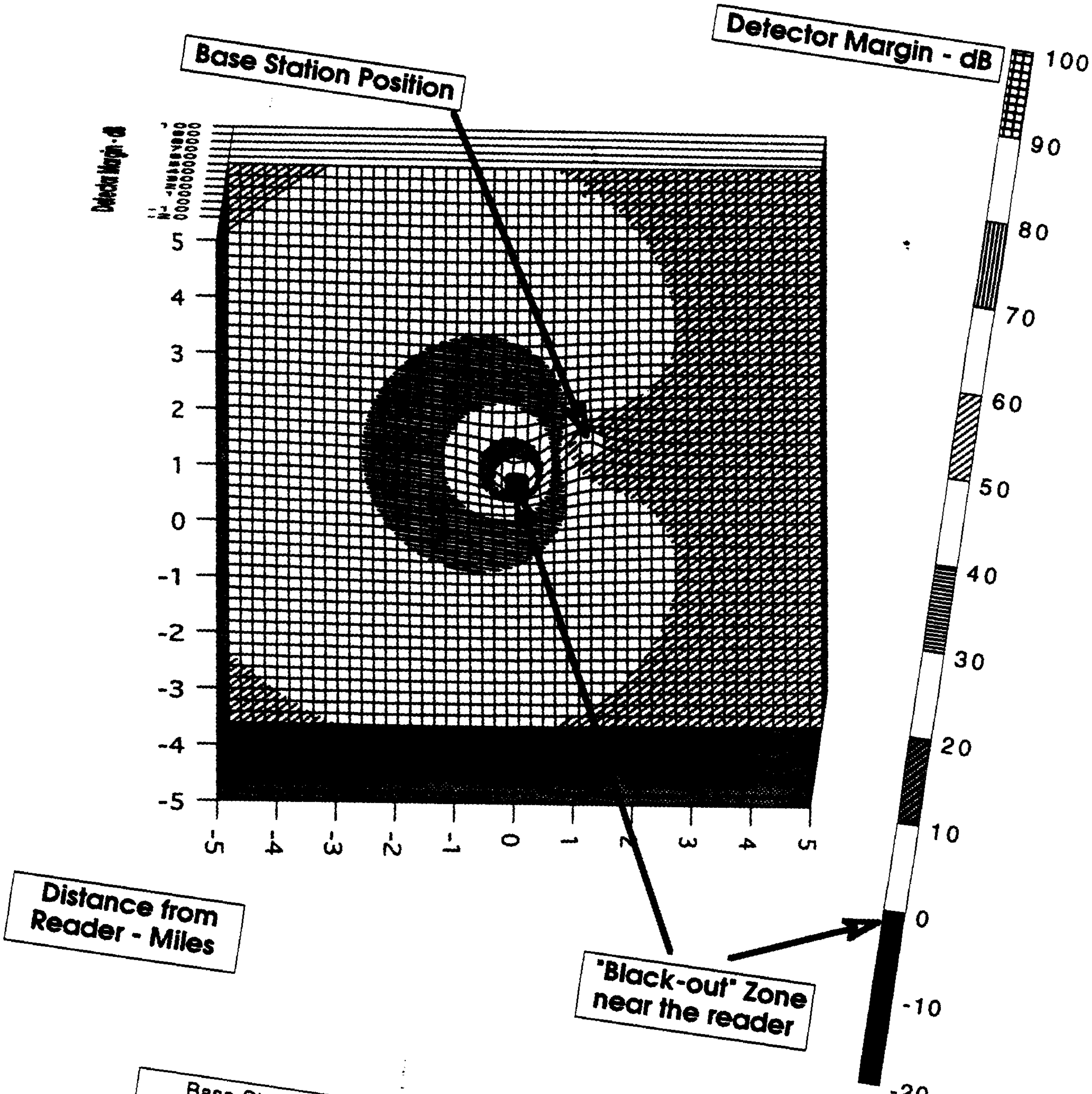
			% decrease in aggregate capacity		
% overhead					
1.000%	0.00%	1.00%	3.00%	7.00%	15.00%
1.189%	0.00%	1.19%	3.57%	8.32%	17.84%
1.414%	0.00%	1.41%	4.24%	9.90%	21.21%
1.682%	0.00%	1.68%	5.05%	11.77%	25.23%
2.000%	0.00%	2.00%	6.00%	14.00%	30.00%
2.378%	0.00%	2.38%	7.14%	16.65%	35.68%
2.828%	0.00%	2.83%	8.49%	19.80%	42.43%
3.364%	0.00%	3.36%	10.09%	23.55%	50.45%
4.000%	0.00%	4.00%	12.00%	28.00%	60.00%

			% increased cost of residual service		
% overhead					
1.000%	0.00%	1.01%	3.09%	7.53%	17.65%
1.189%	0.00%	1.20%	3.70%	9.08%	21.71%
1.414%	0.00%	1.43%	4.43%	10.99%	26.92%
1.682%	0.00%	1.71%	5.31%	13.34%	33.74%
2.000%	0.00%	2.04%	6.38%	16.28%	42.86%
2.378%	0.00%	2.44%	7.68%	19.97%	55.46%
2.828%	0.00%	2.91%	9.27%	24.69%	73.69%
3.364%	0.00%	3.48%	11.22%	30.80%	101.83%
4.000%	0.00%	4.17%	13.64%	38.89%	150.00%



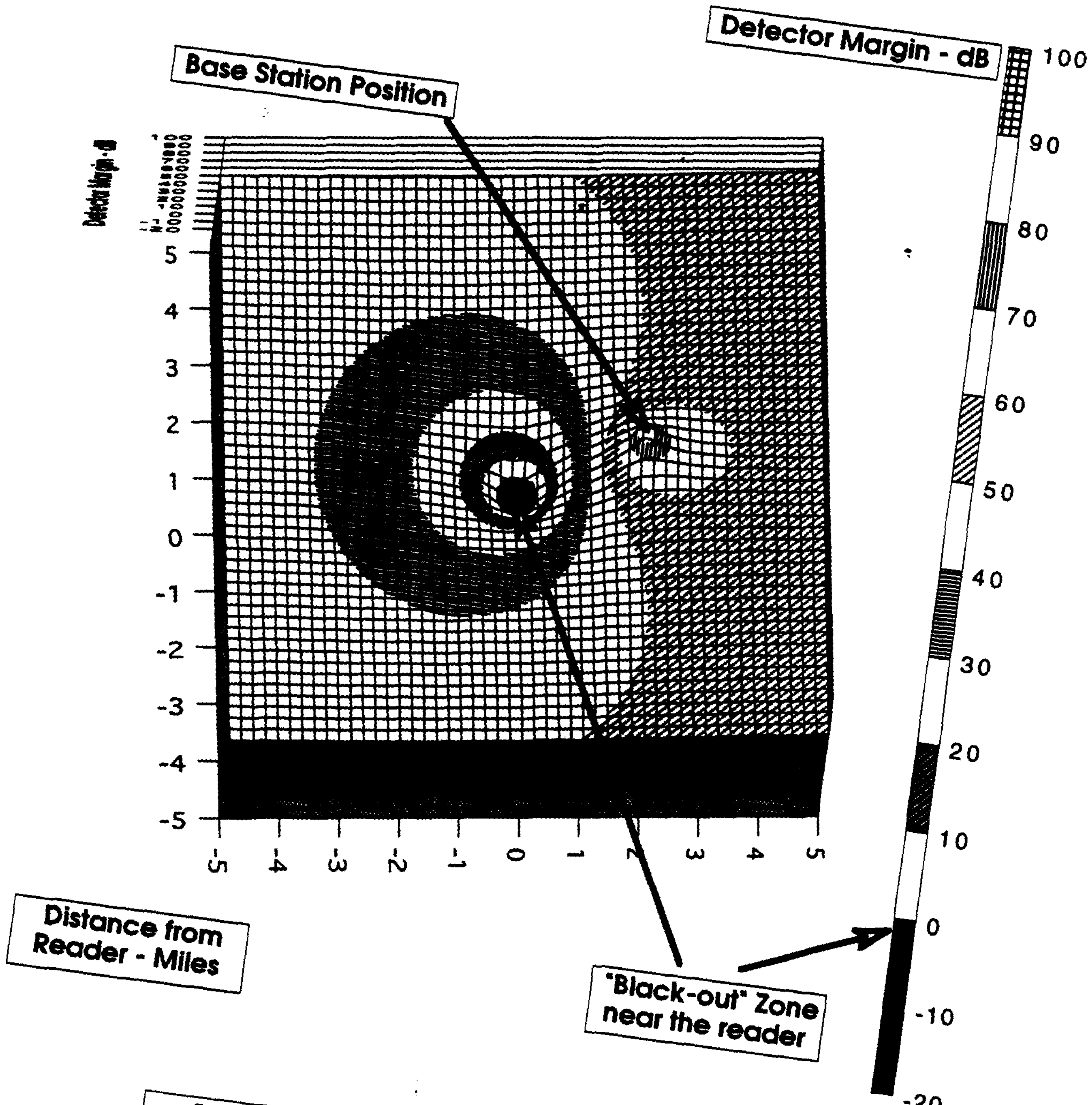
Base Station Power	60.0	dBm
Jammer Power	35.0	dBm
Plot range	5.0	±miles from Jammer

Figure 4
Wide-area Mobile Receiver's Detector-margin @ 50% Communication Closure Probability
Jammer to Base distance 0.5 miles



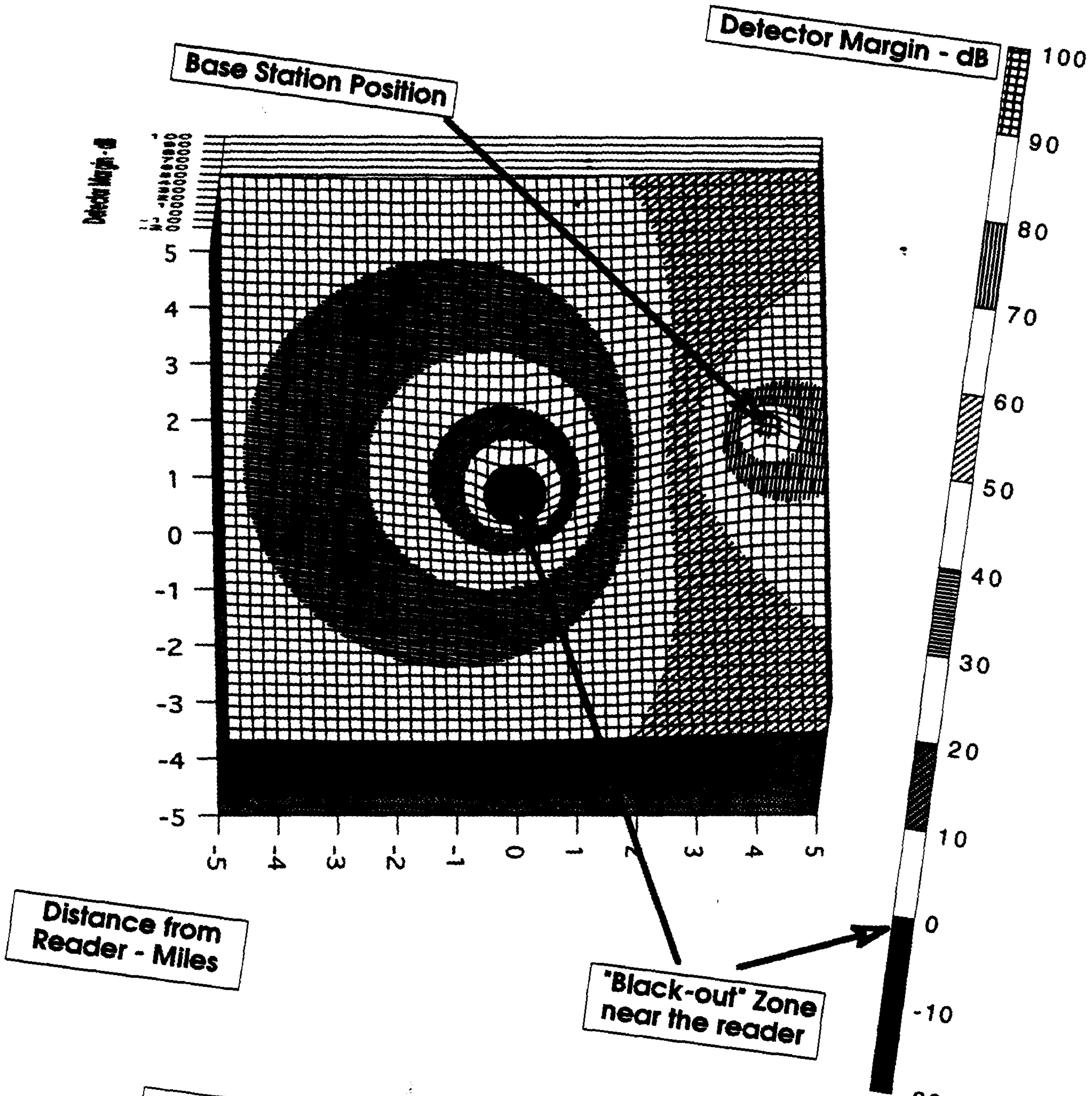
Base Station Power	60.0	dBm
Jammer Power	35.0	dBm
Plot range	5.0	±miles from Jammer

Figure 5
Wide-area Mobile Receiver's Detector-margin @ 50% Communication Closure Probability
Jammer to Base distance 1.0 miles



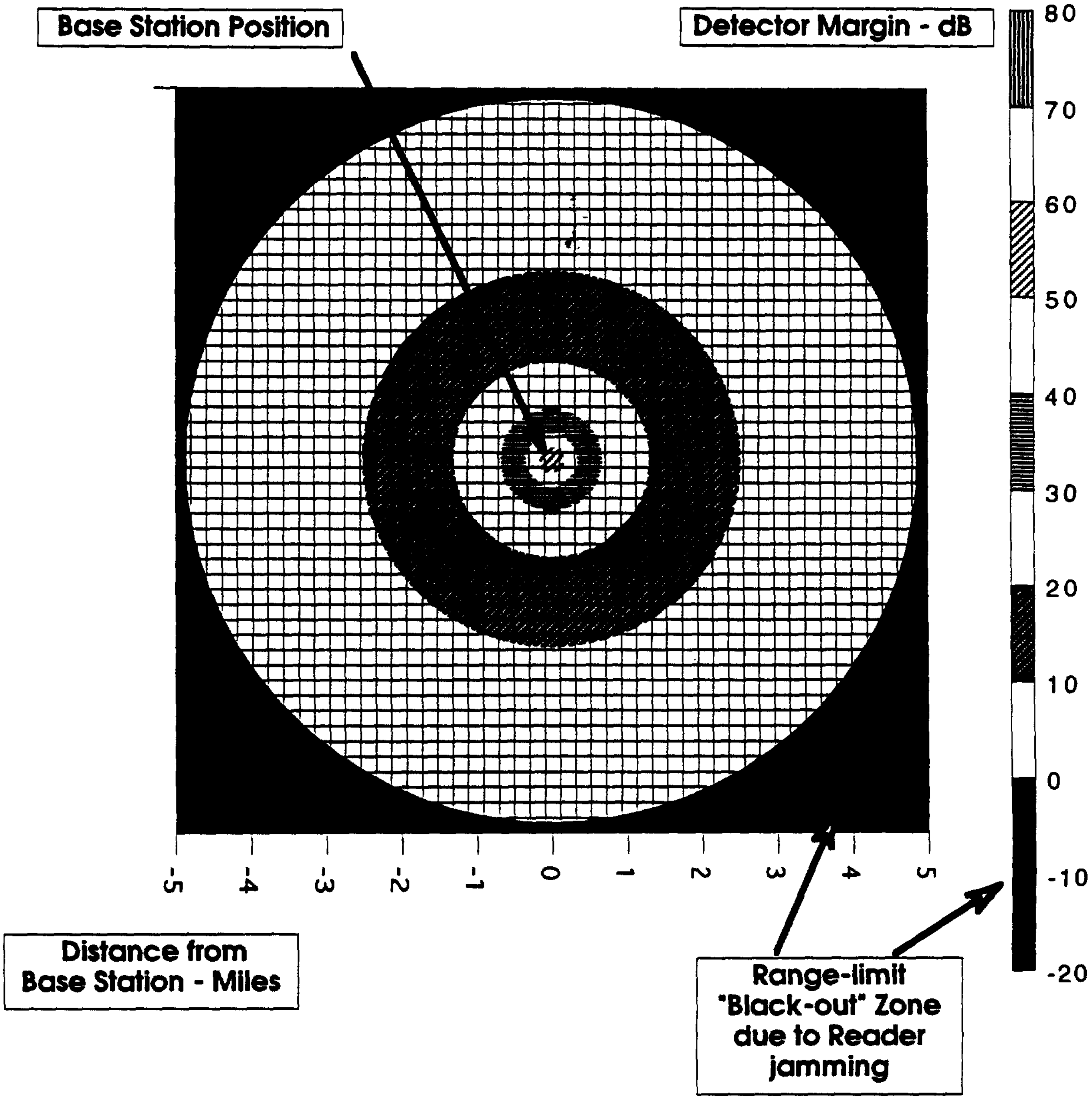
Base Station Power	60.0	dBm
Jammer Power	35.0	dBm
Plot range	5.0	±miles from Jammer

Figure 6
Wide-area Mobile Receiver's Detector-margin
@ 50% Communication Closure Probability
Jammer to Base distance 2.0 miles



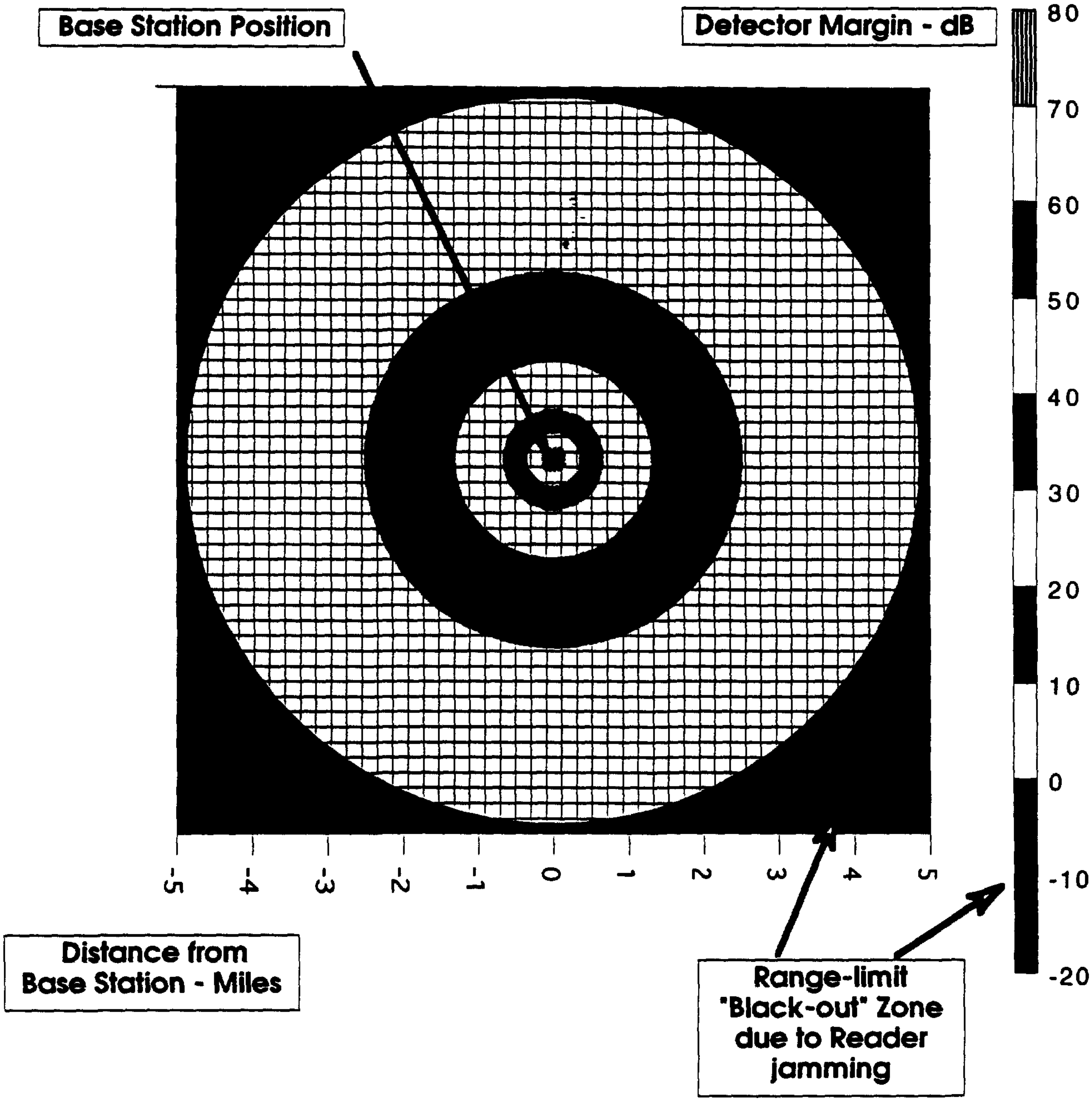
Base Station Power	60.0	dBm
Jammer Power	35.0	dBm
Plot range	5.0	±miles from Jammer

Figure 7
Wide-area Mobile Receiver's Detector-margin @ 50% Communication Closure Probability
Jammer to Base distance 4.0 miles



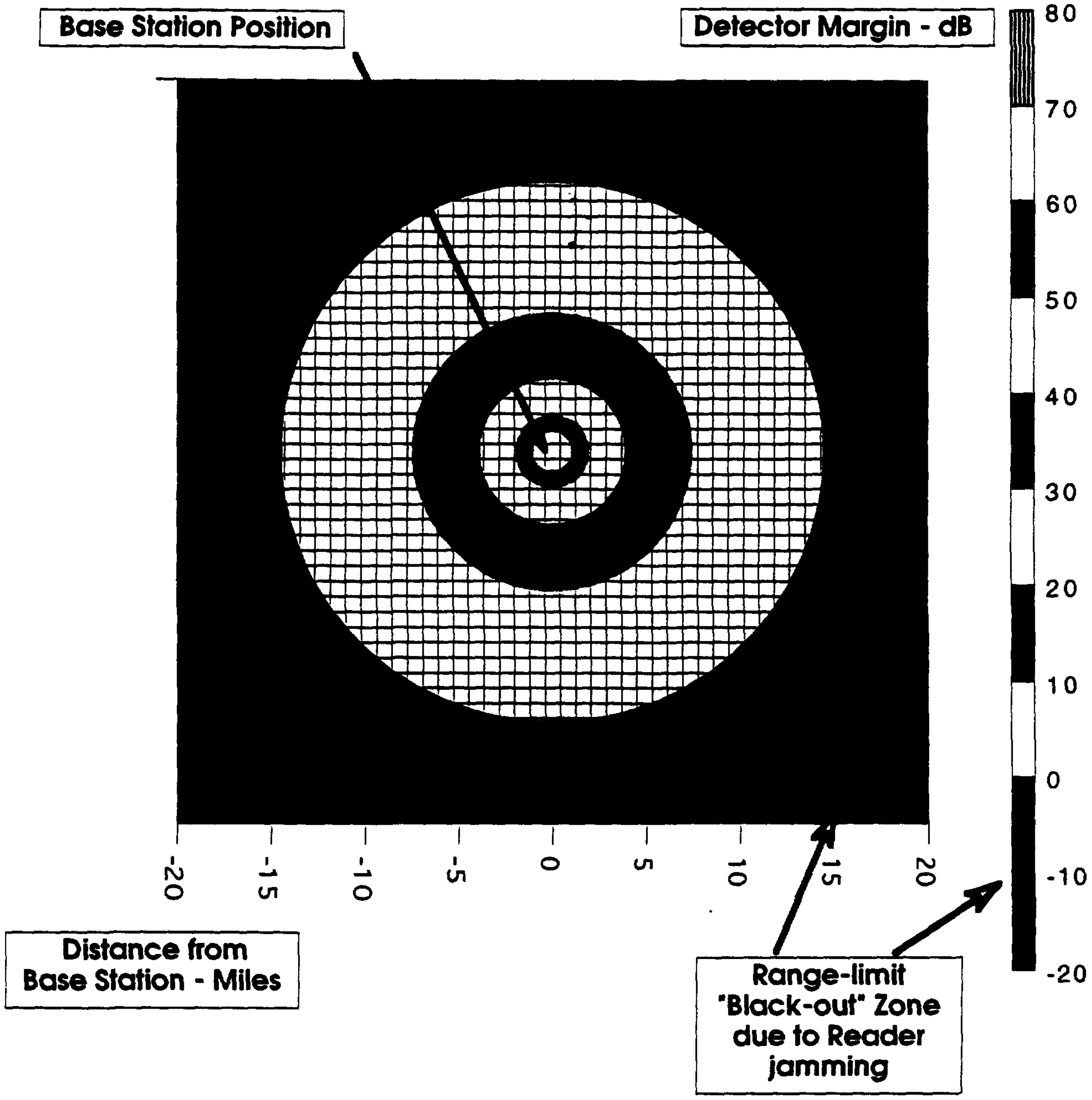
Power-mobile	48.0	dBm	Mobile ht	3	meters
Jammer Power	35.0	dBm	Jammer ht	3	meters
Plot range	5.0	±miles from Jammer	Base ht	30	meters

Figure 8
Wide-area Base Receiver's Detector-margin
@ 50% Communication Closure Probability
Jammer to Base distance 0.5 miles



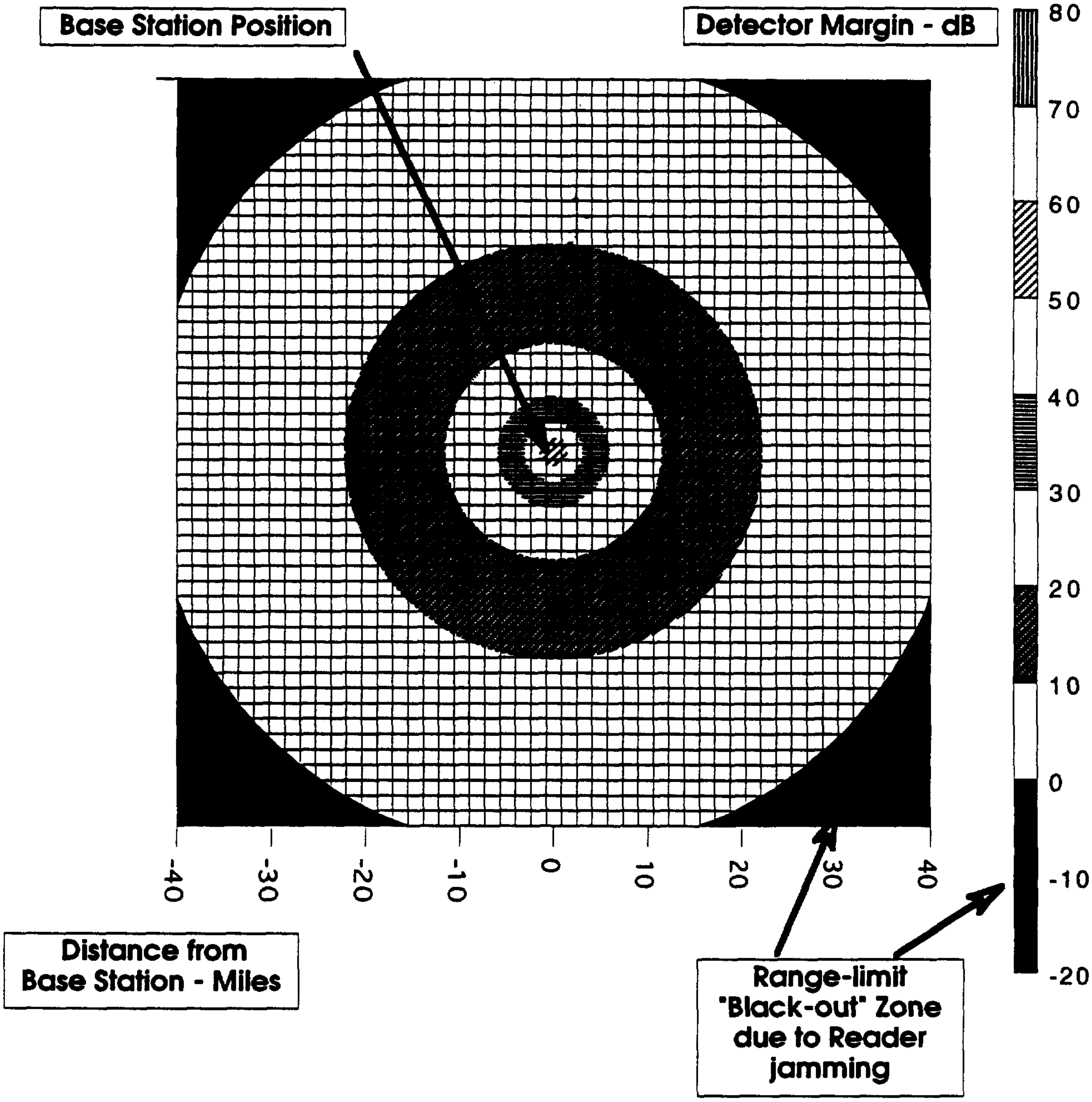
Power-mobile	48.0	dBm	Mobile ht	3	meters
Jammer Power	35.0	dBm	Jammer ht	3	meters
Plot range	5.0	±miles from Jammer	Base ht	30	meters

Figure 9
Wide-area Base Receiver's Detector-margin
@ 50% Communication Closure Probability
Jammer to Base distance 1.0 miles



Power-mobile	48.0	dBm	Mobile ht	3	meters
Jammer Power	35.0	dBm	Jammer ht	3	meters
Plot range	20.0	±miles from Jammer	Base ht	30	meters

Figure 10
Wide-area Base Receiver's Detector-margin
@ 50% Communication Closure Probability
Jammer to Base distance 2.0 miles



Power-mobile	48.0	dBm	Mobile ht	3 meters
Jammer Power	35.0	dBm	Jammer ht	3 meters
Plot range	40.0	±miles from Jammer	Base ht	30 meters

Figure 11
Wide-area Base Receiver's Detector-margin
@ 50% Communication Closure Probability
Jammer to Base distance 4.0 miles